Energy Research & Social Science 84 (2022) 102354

Contents lists available at ScienceDirect

Energy Research & Social Science

journal homepage: www.elsevier.com/locate/erss

Perspective

Energy governance as a commons: Engineering alternative socio-technical configurations

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ARTICLE INFO

Keywords:
Commons
Energy politics
Collaboration
Post-growth
Energy internet
Peer-to-peer

ABSTRACT

Transitioning into a sustainable energy system is becoming ever more pressing as the reality of an anthropogenic ecological crisis becomes difficult to ignore. Due to the complexity of the matter, proposed solutions often address the symptoms of the current socioeconomic configuration rather than its core. To conceptualise possible future energy systems, this Perspective focuses on the disconnect between science and technology and engineering studies. On the one hand, this disconnect leads to social science research that passively critiques rather than contributes to tackling societal issues in practice. On the other, it produces technical work limited by the incumbent conceptualisations of economic activity and organisational configurations around production without capturing the broader social and political dynamics. We thus propose a schema for bridging this divide that uses the "commons" as an umbrella concept. We apply this framework on the hardware aspect of a conceptual energy system, which builds on networked microgrids powered by open-source, lower cost, adaptable, socially responsible and sustainable technology. This Perspective is a call to engineers and social scientists alike to form genuine transdisciplinary collaborations for developing radical alternatives to the energy conundrum.

1. Introduction

The issue of transitioning into a sustainable energy production system is becoming ever more pressing as the reality of an anthropogenic ecological crisis grows increasingly difficult to ignore. Due to the complexity of the matter, proposed solutions often address the symptoms of the current socioeconomic configuration rather than the core of it. Creating an entirely different energy system would not only require reconceptualising the material and digital infrastructure but also the political economy that permeates it. The two are inextricably linked [1,2].

As decentralised grids are becoming more prominent with the advent of renewable energy technology, existing models of energy production are diversified. However, energy production management remains highly centralised [3]. While the liberalisation of the energy market is accompanied by a narrative of empowered users/producers engaging along large utility providers or small-scale rooftop installations, the system of production relies on economic and political relations motivated by profit maximisation and propelled by fossil fuels [4]. This, arguably, propagates two conditions.

First, and most dire, it prolongs the unsustainability of viewing energy as a commodity to be produced and sold rather than a fundamental factor of production without which economies would grind to a halt [5,6,7]. This basic assumption of mainstream economics, inadvertently, obfuscates all kinds of consequences associated with energy consumption and energy technologies, such as environmental degradation and the social/health impact on local communities. Second, citizens are often disengaged from the entire process of producing and consuming energy. Energy, seen as a commodity, can hide the fact that energy production exists at the expense of other humans and local

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https://doi.org/10.1016/j.erss.2021.102354
Received 27 July 2021; Received in revised form 11 October 2021; Accepted 14 October 2021

environments elsewhere in the global economy [8,9,10]. Additionally, current options for energy access provide a false empowerment for citizens to participate at the very last level of a stratified and unequally distributed system, designed to favour those with the most economic and political power [8]. Engaging at all stages of energy production may enable citizens and researchers to re-evaluate the costs and impact of energy production, rather than envisioning energy as "free" [11].

The exclusion of local communities can be witnessed in the massive renewable energy projects developed in environmentally rich and sparsely populated areas [12,13]. These projects are not under the control of local populations, which receive none of the benefits of the energy produced as they are for profit, private investments [14,15]. Instead, communities experience the impact of such investments on their natural surroundings, such as deforestation [16], with the only option available to them being protests or relocation (typically to urban areas). Protests are often violently suppressed by local governments protecting the interests of powerful social groups, often foreign conglomerates.

The recent fall in prices of renewable energy technology has allowed individuals to produce energy themselves to a smaller degree and capacity, but typically within profit-based market mechanisms encouraging them to produce energy for the centralised grids rather than to cover their own energy needs. After all, legal and economic structures often prohibit complete energy autonomy and autarky [17,18]. The decline in prices on solar power over the last decades would likely have been impossible without a mass relocation of production facilities from North America and Europe (e.g., Germany) to Asia (e.g., China), where wages are lower and environmental regulations, notably on greenhouse gas emissions, are comparatively deficient [4]. Thus, both the production and usage of renewable energy technology are intertwined in the current socioeconomic configuration. To address the energy conundrum, a radical reconceptualisation of how we think about energy production is therefore required. There is an urgent need to transition to an energy system that not only produces energy in an environmentally sustainable way, but also socially [17,18]. Such efforts, we argue, can be greatly strengthened by bridging the gap between social scientists and engineers.

The paper is organised as follows: Section 2 discusses how the social science and engineering disciplines operate independently of each other. Section 3 proposes a schema for bringing engineers and social scientists under a commons-oriented framework. Section 4 then applies this framework into the electrical engineering processes of developing technologies for production and distribution of energy. Section 5 concludes our theoretical exercise by inviting scholars (engineers and social scientists alike) to reach out and form genuine transdisciplinary collaborations for developing radical alternatives to the aforementioned problems.

2. Bridging the gap between social science and engineering

Social scientists interested in technology studies adopt a wide variety of epistemological and methodological perspectives to understand what prolific science fiction writer Ursula Le Guin [19] identifies as "the active human interface with the material world." Indeed, technology is such an integral part of human existence that it merits equal, if not more, critical examination along with politics, economics, culture, and other manifestations of human activity. To that end, social scientists, who reject the notion that technology is value-free and deterministically evolving, attempt to uncover those underlying social interests, values, and human-environmental relations that govern it.

And yet, rarely (if ever) are social scientists invited to provide their insight in the further development of technology much like economists are consulted regarding economic policy. They are typically relegated into the role of passive observers which provide, in hindsight, their interpretations on how certain technological artefacts and systems impact society after their introduction. Social scientists further provide thoughtful criticisms of the innovation systems and the structural considerations that lead to technological innovation, which is deemed inadequate in tackling our current predicament and offer insight in ameliorating this [11,20,21]. However, that insight does not typically escape their academic bubble. Whilst several approaches to redesign energy systems, like value sensitive design or responsible research and innovation and the energy justice framework, have been developed [22,23], these approaches rarely reach those social groups most active in the design of technology — primarily, engineers of all sorts.

On the other side, engineering schools, like most of the institutions of higher education, often train a specialised labour force following the tendencies mostly determined by economic factors indicated by big industries, consulting companies and think tanks [24,25]. In this sense, the education of engineers is predominantly technical-driven and barely touches upon critical societal issues. Engineers then become experts in a very narrow domain. For instance, one is an expert in designing hydropower generators without understanding how such devices impact the different places these artefacts will be deployed, the social conditions of workers who produce them, or the environmental impacts associated with extracting the necessary raw material.

Clearly, the activities of different engineers need to be reconfigured. A specific discipline that focuses on this is "Systems Engineering" [26]. In a positivist manner, systems are defined as a set of elements, possessing their own attributes, which are combined to perform a predetermined function [26]. The system is then linked to everything else (i.e., its environment) by input–output relations. By using these methods, systems engineers plan new products, organise production processes, and propose cost-benefit analysis of outsourcing. Systems engineers are then trained to see the big picture, working as an integrator to guarantee that a given system is successfully performing its function. There is one problem here: systems engineers are also employees who have a specific function in the division of labour, having the same fate as other specialised engineers. Engineers produce solutions within narrowly defined parameters, typically revolving around the profitability of the employer.

As a rule of thumb, a given system needs to work to accomplish its function and anything else that makes it more difficult is seen as constraints or boundary conditions. For engineers employed by private corporations, the situation is usually more challenging because the (short-term) profit of shareholders is ultimately the aim of any system that is produced and deployed. There is also a fundamental theoretical problem in systems engineering. That is the modular nature of the articulation between the system, its possible subsystems, and its respective environment. Systems engineers will model their systems as "boxes" linked with lines of inputs and outputs, without defining the levels and instances that represent how a particular system is articulated within its own physical and social environment.

This paper is authored by an expanding collaborative network of engineers and social scientists galvanised by the escalating social and environmental crises across the planet into developing technological solutions, potentially imbued with the values of sustainability and social inclusion. It is a call to other engineers and scholars to reach out and collaborate in this most critical of times. Here we offer a two-level holarchic approach that utilises the facts stated by systems engineering as our starting points, i.e., our raw materials, to propose a different approach in conceptualising functioning systems with multiple goals from different actors. The idea is to demarcate a particular functioning system, marking its boundaries based on a peculiar operation that defines that particular system as such [27].

At the first level, the analysis is centred at a specific system and its functions. The focus is placed on the system's inner workings and the impact of the environment upon the system's functions. This includes aspects internal to the system operation (e.g., poor maintenance, lack of trained personnel) and external (e.g., hurricanes, political crises, social unrest). These manifestations might be direct or indirect with respect to a specific function, while their effects may vary in different levels. At the second level, all else is considered, i.e., the environment where the particular system exists. It is positioned within the complex, social and natural whole, articulated in dominance (some effects are stronger than others).

The first level is analytical by functionally generalising the system. It "isolates" the system from its context and examines its components and operation. The second level is a synthesis and rearticulates the system in the whole, positioning it as an integral part of its particular natural-social surroundings and examines their interplay. This is a distinction that led philosopher of technology Carl Mitcham [28] to separate between what he called "engineering" and "humanities" philosophy of technology. It also reflects Feenberg's dual instrumentalization theory of analysing technological biases. Very briefly, the first level of instrumentalization breaks down technological artefacts into their most basic components, while on the second it re-contextualises them the social world embedded with values, meanings, and goals [29]. Much like with instrumentalisation, our two nested holarchic levels are conceptually interlinked but analytically distinguished. By bridging these mirroring streams, we see engineers leading research on the first level and social scientists on the second.

We, therefore, attempt to merge a critical philosophy of technology with the language of generality and modularity, easily understood in systems engineering. We also wish to broaden the scope of the social elements to consider in designing alternative systems. This includes aspects of how technological systems and artefacts are at some level organised by the incumbent mode of production. This leads us to explore alternative production systems to radically re-imagine our energy production system from the ground up.

3. The commons as the binding element

The commons are social practices of creating and/or governing a resource through the institutions that a community of producers or users creates and manages [30,31]. So, the commons consist of a community, a resource, and the management rules that the community forms to co-create and/or co-manage this resource [31]. We claim that the commons could provide an umbrella framework for constructing a holistic and sustainable alternative to the current socio-economic configuration which permeates virtually all facets of human activity, i.e., profit maximising market relations. The commons may also form a boundary object, a mutual language, to enable collaboration across multiple disciplines in the pursuit of radical solutions. It has certainly formed the unifying factor for this team of researchers/co-authors coming from diverse disciplines.

Elinor Ostrom received the 2009 Nobel Prize in Economics for her groundbreaking work on the commons. Across her academic career, Ostom developed a framework for systematising and understanding the complex and multiscalar interaction taking place in the systems managing a shared resource [32]. The framework offers tools and concepts for interdisciplinary work in analysing such systems, albeit primarily by social/political scientists and economists. The framework has been built upon in multiple applications such as analysing energy transitions [33] as well as climate and energy policies [34], designing methods to empower community solar energy projects as commons [35], and the studying the effect of digital technologies on energy sharing projects [36]. Our approach, with the addition of engineering perspective, attempts to also take a step further and incorporate the commons into the design of the technological artefacts and infrastructure we discuss.

To that end, we adopt commons-based peer production as our template, first observed in digital production such as software and later to physical production too. Briefly, it involves the collaboration of individuals, often in large numbers and across large distances through the Internet, to produce artefacts which are considered commons, i.e., shared public good, under community-defined organisational structures [37]. These artefacts are geared towards satisfying needs rather than financial profit for those involved. The GNU/Linux kernel and Wikipedia are two of the most prominent examples.

At the same time, the emergence of energy cooperatives has brought commons-oriented governance approaches and resource management practices into the energy production sector [38,39,40]. In a previous paper, inspired by these developments and fully embracing the political economy of the commons, some of us developed a novel technical framework for proliferating such energy production models in society [41]. We indicated that the expected increase of renewable energy production may open a window of opportunity to treat electricity as a commons in a system called "Energy Internet". In this case, the flow components, namely solar radiation and wind, would have a local zero marginal cost [42]. With a specific management system, this would result in a peer produced energy where all members share their generation and storage units, while the demand management would be directly related to the needs of the users, not mediated by a commodity-form or a restriction of access.

In the case of energy systems, most components (e.g., towers and cables), operating components (e.g., generators, power electronic devices) and flow components (e.g., coal, oil and natural gas) are highly complex commodities produced within global capitalist relations contingent on fossil fuels. As such, they, in some sense, are the dominant socioeconomic configuration [2,4]. Through our previous essay [41], we outlined the basic structural and operating components necessary for the transition to a system which shows significant potential for feasibility and sustainability compared to proposed solutions stemming from the incumbent socio-economic configurations. These can be very broadly divided into two categories. First, the software-defined elements (usually labelled as "immaterial"), which entails the digital technologies managing energy flows; a topic we expanded upon. Second, the raw material and physical components, for which we have yet, offered little on how they could be extracted and peer produced as a commons. In this paper, we apply the engineer/social scientist collaboration framework we discuss above onto the hardware aspect of our envisioned system.

4. A hardware perspective on grid of microgrids

Our proposed commons-oriented Energy Internet builds on the concept of microgrids. In a software defined energy network, multiple microgrids (small local, often independent, grids) connect with each other to share electricity as a commons. These interactions are optimised and managed through packetised energy management via a communications network infrastructure, based on similar principles as the Internet. The technological expertise for the digital infrastructure is already largely available, albeit with primary attempts to be applied in market-based relations whereby energy is treated as a commodity amongst distributed producers and consumers.

Applying this infrastructure in a commons framework, i.e., treating energy and energy infrastructure as a communal resource rather than a commodity, simplifies several structural difficulties associated with current proposals around distributed energy production. The commons framework removes the complex financial considerations that sit on top of an, already, complex network of decentralised energy transfer. It also makes the value of energy sharing more transparent and accountable for citizens, avoiding an overwhelming complexity of market dynamics and equilibria that shallowly represent citizens as rational selfish agents.

Further developing our proposal, we provide some insight on how the hardware elements could be conceptualised within the political economy context this technological infrastructure is built on. In that sense, this aspect would also be treated as a commons, which implies certain characteristics attached to the technological artefacts themselves. First and foremost, they would be open-source. All information necessary to reproduce and operate the artefact would be available freely without any strict intellectual property restrictions. It would also mean that the standards such technologies adhere to are also open and interoperable, enabling technology and knowledge to be transferred simply whilst maintaining a common set of system variables.

These characteristics are encapsulated in the production configuration described as "design global, manufacture local" or "cosmolocalism". Knowledge is produced and freely shared globally through digital technologies while material production takes place locally on a smaller scale, ideally in open and collaborative spaces with communal manufacturing infrastructure [43,44]. This configuration has been observed in varying types of production activities from small-scale wind turbines and prosthetics [44], to farming tools [45], and even buildings [46]. Applied to energy, it would enable local manufacturing communities to not only use global designs for technology available in the commons, but also develop their own local designs adapted to local market capacities and environmental conditions. For these designs to offer a sustainable alternative to the global political economy of energy infrastructure, they would have to be adapted to the bioregional capacity and local accessibility of raw materials and recyclable components. These designs can then be shared back with the commons, growing the knowledge-base in the area. Energy technology projects displaying these features have been steadily emerging in recent years across the world[1].

Micro-hydropower development in Nepal is an excellent example of how open-source, commons-based knowledge using clear standards can be used to develop local energy manufacturing enterprises [47]. During the 1960s and 1970s, donors aimed to develop Nepal's manufacturing industry by building capacity focused on local requirements, namely hydropower systems. Using established global turbine designs from international development agencies, local companies developed their own versions of these designs to meet with available materials and processes and local standards for electrical output. In the intervening years, these turbines have undergone minor developments, such as improvements to the design to improve reliability, with an increasing number of manufacturing companies joining the market to supply local consumers [48].

A 14 kW off-grid microgrid near the city of Belém, Brazil, offers additional insight (Authors' empirical account). Proprietary equipment built in the Global North was installed as the technical backbone of the microgrid. The equipment had to be specially ordered into the country. However, within 3 years, half of the equipment failed due to environmental conditions. There was no option to repair the equipment as its patented design obscured relevant information which would enable local industry to engage with the problem. Alongside this, the components within the design were not available in the local marketplace to replace failed components. The final option for the community was to return it to the manufacturer, however this was prohibitively expensive for the low-income consumers. The community now owns a many thousand-dollar "white elephant" that is of no use to them.

Recently, the same team in Brazil, which an author of this essay closely collaborates with, has been developing a more robust microgrid. It still uses off-the-shelf equipment built in the Global North but is modular, enabling the system to be built and expanded gradually. The standards for the system required an operating grid voltage of 24 V DC. Each piece of equipment has a lower overall cost and is readily available in the local market, meaning that if one unit fails, it can be replaced more simply. They also followed principles similar to those proposed for "Design for Localisation" [40], working with the community to derive local product requirements, developing an appropriate design based on local enterprises, and testing the system in their field laboratory before installing with the community.

Design for Localisation applies the constraints placed upon the system by local manufacturing capability, such as local manufacturing process availability, or material accessibility. An alternative to using off-the-shelf equipment would be to source equipment from the local industry. The major challenge with this solution is the need for the local industry to have access to the required designs and raw materials. These designs could be developed in-house if the capacity exists. A design developed within a commons framework, can be used and modified by local industry to match local conditions and standards. Therefore, this approach would further adapt the design global, manufacture local or cosmolocal framework to encourage local experts to include local material/component availability, environmental conditions, or regulatory and system requirements. This is a critical principle to ensure product success in the local environment. The local industry involvement in the manufacturing and assembly of the system would enable repair and maintenance, elongating the life of units by ensuring lower cost repair capability.

Going back to the microgrid network concept, once a microgrid is formed, combining the appropriate renewable resources and storage elements for a community can be used to supply local loads to provide services they require (Fig. 1). With multiple generators, the redundancy of the system can increase, improving the resilience of the services provided to the community. If there are several microgrids, these can be linked together to form a more resilient energy system for the interconnected energy communities (Fig. 2). Through this topology, communities would be able to exchange energy with each other during times of excess or high demand.

If similar commons-based technologies were used in each of the microgrids, local enterprises, as discussed above, could supply these energy communities. The commons would also enable capability development and tool transfer for these manufacturing communities, building on existing knowledge and capacity within the local area. This would then provide a sustainable, locally appropriate solution for energy solutions and technologies.

This approach would further empower communities to run their own demand-response mechanisms and demand-side energy self-management systems that prioritise the needs of the energy community. In the context of energy autarky, the community would set its own decarbonisation goals aligned to the local social/environmental context, while inter-operating with external components of the power grid to retain system stability. Such an alternative management does not require giving up control and personal sensitive data to power utilities. Instead, communities can rely on open hardware (sensors, thermostats, appliance controllers) and open-source software solutions (interconnected home energy management systems) that can easily deploy as commons at home to participate in a bottom-up coordinated energy self-management. Matching supply–demand, shifting power demand to times that better serve the community, consuming more at times of higher availability in renewable energy, or even fair access to energy for all individuals would be more possible. The conceptualisation and feasibility of such alternatives has already been demonstrated [49].

Today, technological artefacts, including energy technologies, are produced in highly complex commodity chains. Even the simplest

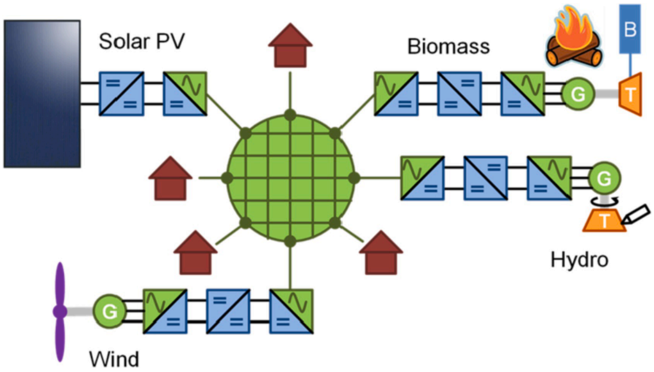

Fig. 1. Renewable-powered microgrid, using local resources to power local community loads.

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[1] For a non-exhaustive list of such projects see here: https://opensustain.tech/.

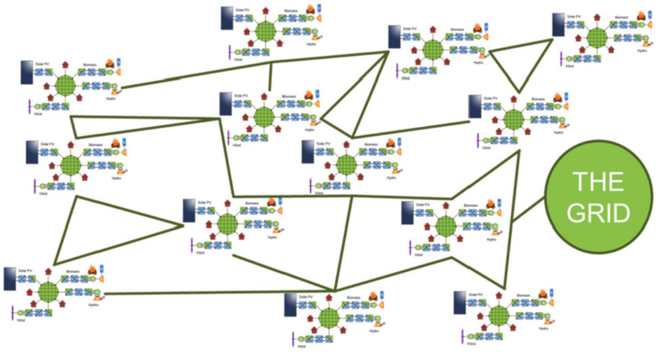

Fig. 2. Multiple microgrids interconnected to form a grid of microgrids, more robust, resilient, and able to connect and supply/consume power from the power grid if necessary.

artefact, such as a computer mouse, is associated with at least twenty different materials extracted from all around the world [50]. Fig. 1 does not show how the energy technologies presented are currently contingent upon a global social system (i.e., the world economy) to extract, process, transport, and assemble the raw material into artefacts such as solar panels, wind turbines, electric generators, and more. The two cases from Nepal and Brazil demonstrate how commons-based peer production is currently reliant upon infrastructure produced in this world economy, even as the infrastructure was donated and abandoned in the respective cases we presented.

We suggest that these cases highlight at once a problem and a potential solution. On the one hand, the reliance upon sophisticated (high-tech) energy infrastructure is associated with numerous social and ecological problems. Moreover, it is abundantly clear that the total amount of energy-matter process in the world economy must drastically be reduced to avert the potentially catastrophic effects of climate change, the rapid loss of biodiversity, and the transgression of planetary boundaries [51,52]. On the other hand, the two cases clearly demonstrate how already existing material components and infrastructure can be used, repaired, or reshaped to be used as a basis for the emerging commons-based peer production – an entirely new mode of production.

Arguably, there is already enough "technomass" in the world for suggesting the material feasibility of commons-based peer production based on regional material accessibility (for a description of the technomass indicator, see Inostroza [53]). For instance, material extraction has increased from 12 Gt/year in 1900 to 89 Gt/year in 2015; a figure unprecedented in human history [54]. No small percentage of this material extracted is used to construct and maintain ecologically devastating fossil infrastructure throughout the world that could (or must) be dismantled. Such infrastructure, including coal power plants, oil rigs, gas pipelines, nuclear power plants, processing facilities, could be dismantled, redesigned and reworked. The resulting components and raw materials could be channeled from the proprietary mode of production to the commons-based peer production. This is essentially what happened both in the Nepalese and Brazilian case, as existing infrastructure was transferred from one social configuration to another. Such efforts are a particularly fertile ground for future collaboration between engineers and social scientists, as it demands engineering expertise on how to dismantle, rework, design, and install sophisticated technological infrastructure, while also demanding expertise on how to navigate complex networks of social interests, behavioural obstacles, and financial and juridical norms and regulations.

5. Conclusions: a call to action and collaboration

This paper has provided a foundation for what we have identified as a fruitful, and indeed necessary, collaboration between two otherwise separate domains of expertise in sustainable energy production. The multifaceted ecological crisis must arguably be dealt with in a collaborative manner, wherein the analyses and theories of social scientists are prompted to be useful in the practical contexts of engineering. In the same collaborative spirit, engineering must seek to draw insights from the social sciences showing how particular social configurations are core determinants for how, whether, and why a particular design or artefact is pursued. Such configurations are ultimately as necessary as any material component for the functioning of a particular energy technology.

We have argued that the most fertile binding element for this collaboration is the commons – particularly commons-based peer production – wherein energy is treated not as a commodity but as a physical necessity for living systems. Applied to the question of future sustainable energy production, we have presented two concrete examples, one from Nepal and one from Brazil, showing how engineering expertise and social science expertise can be combined to empower communities to shift their mode of energy production away from the dominant socioeconomic configuration based on the profit motive and propelled by fossil fuels. Even if the necessary infrastructure is currently being manufactured in a highly unequal and ecologically damaging global world economy, the two examples demonstrate how such infrastructure components can be transferred from one social system to another.

This is a fertile ground for future collaboration between engineers and social scientists towards a socially and ecologically sustainable world. However, change will not come simply from increased collaboration between engineers and social scientists. Energy transitions are deeply uncertain and complex transformation processes that involve different actors [55]. Participatory exploratory approaches, which combine both qualitative and quantitative exploratory aspects, could be used for long-term planning in energy transitions [55].

Further, while we primarily focused on the technological possibilities of placing the commons in the middle of such a partnership, there are social elements and potential problems with the organisational and production practices around energy governance as a commons. Issues like gender and gender imbalances, economic access, cultural specificities need to be accounted for and addressed in the energy commons framework. Clearly, much work is yet to be done to concretise the suggestions that we have presented. We shall certainly work towards that goal. Meanwhile, we wish to extend an invitation to scholars and engineers to join us in conceptualising and producing structural alternatives for energy sustainability.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgement

C.G. and V.K. acknowledge funding from the European Research Council under the European Union's Horizon 2020 research and innovation programme [grant agreement No 802512]. P.H.J.N. acknowledges funding from the Academy of Finland Research Fellow EnergyNet project [n.321265/n.328869].

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